# Major Transgressive-Regressive Cycles in Middle to Late Visean Rocks of Nova Scotia

by P.S. Giles

Nova Scotia
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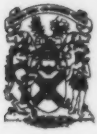

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# MAJOR TRANSGRESSIVE-REGRESSIVE CYCLES IN MIDDLE TO LATE VISEAN ROCKS OF NOVA SCOTIA

by

P. S. Giles

Hon. Ronald Barkhouse, Minister
John J. Laffin, P. Eng., Deputy Minister

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## ABSTRACT

The Windsor Group of Middle to Late Visean age comprises as many as seven formations, the equivalents of which can be recognized throughout Nova Scotia. These can be assigned to five major transgressive-regressive cycles, the earliest of which is characterized by the ascending sequence carbonate-anhydrite-halite-siltstone. Adjacent to paleo-basin margins, terrigenous rocks complicate this sequence. Cycles 2 to 5 are regionally more variable than is the first major cycle, but are typified by numerous laterally extensive marine carbonate members, associated with rocks typical of arid tidal-flat and continental sedimentary environments. Cycle 5 includes rocks assigned to the lowermost part of Canso Group (Visean-Namurian).

The lower boundaries of the cycles, defined using lithologic criteria, coincide reasonably with biostratigraphic boundaries determined by independent studies of macrofauna, calcareous Foraminifera, conodonts and miospores. This coincidence suggests that the cycles are bounded by approximate time planes. Similar major transgressive-regressive cycles have been recognized in the Dinantian of Britain, where they correspond approximately with recently defined stages. Biostratigraphic correlation of the Windsor cycles suggests that Cycle 1 is equivalent in age to the Arundian and possibly the Holkerian stage. Cycle 2 equates in age with part or all of the Holkerian, and possibly extends into the Asbian. Cycles 3, 4, and 5 appear to be within the British Brigantian stage.


## INTRODUCTION

The Windsor Group of Middle to Late Visean age is characterized by marine evaporites including gypsum, anhydrite, halite and minor potash, by nonmarine to marginal marine, fine grained terrigenous rocks, and by fossiliferous marine limestone and dolostone. Widely distributed throughout central and northern Nova Scotia (Fig. 1), rocks of the Windsor Group contribute substantially to the mineral industry in the Province, primarily through the provision of large reserves of gypsum and halite.

As a result of recent exploration for base metals in the Windsor Group, an abundance of subsurface data has become available and it is now possible to refine and document in greater detail the lithostratigraphic subdivisions of the Windsor Group. The regional stratigraphic framework which emerges from these data is summarized in this paper.

Within this framework, five major cycles of marine transgression and regression can be recognized. These major cycles provide a broader perspective of the Windsor Group than that presented at the formational level, and also provide time-significant subdivisions appropriate for paleogeographic reconstruction. The cycles are described and defined for the first time in this paper, and are correlated with similar major transgressive-regressive cycles in Dinantian rocks of Britain using the biostratigraphic data provided through the work of Bell (1929), Stacey (1953), Sage (1954), Moore (1967), Globensky (1967), Mamet (1970), von Bitter (1976), Utting (1978, 1980), Moore and Ryan (1976), Adams (1978), Ryan (1978) and others.

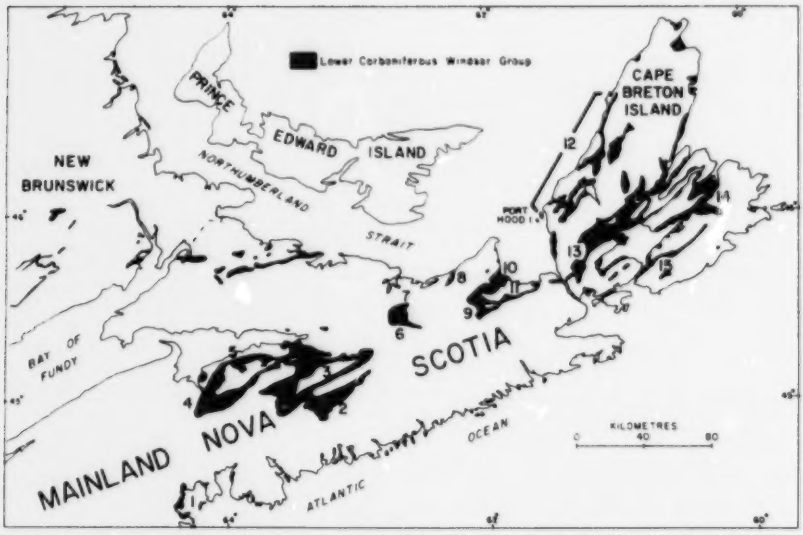



Figure 1. Location map showing the distribution of the Windsor Group (Middle to Late Visean) in Nova Scotia. Numbers refer to the location of the sections shown in Figure 2.

## LITHOSTRATIGRAPHY

### Introduction

The term Windsor Group, as used in this paper, is applied to that succession of Visean marine and nonmarine strata bounded at the base by the lowest bed of marine limestone of the Macumber Formation of Weeks (1948) or laterally equivalent carbonate rocks (Fig. 2), and at the top by the highest bed of marine limestone. Throughout much of Nova Scotia, this definition results in the top of the group being placed at the top of Kennetcook Limestone Member of Moore (1967), or its lateral equivalent, the $E_1$ limestone member (informal term) of Stacey (1953). These boundaries have proven to be generally applicable for purposes of geological mapping (Giles and Boehner, 1979), but are admittedly more rigidly defined than those originally designated by Bell (1929), and differ slightly from those used by previous workers (e.g. Sage, 1954; Moore, 1967).

In areas where the Windsor Group is incomplete at the base due to transgressive overstepping, the base is placed at the unconformity or disconformity separating Visean strata from older rocks (Fig. 2), as recommended by Keppie et al. (1978). In such areas, the main criterion applied in defining the group is that Visean marine carbonate rocks must be intercalated. They need not form the base of the local succession.

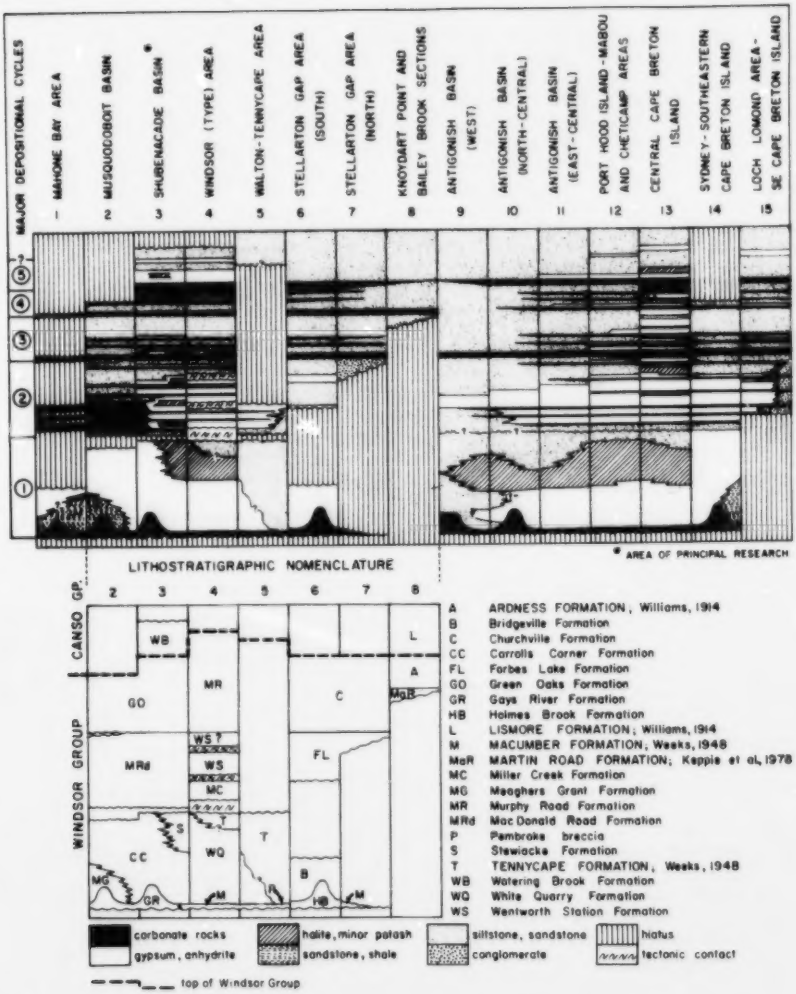



Figure 2. Lithostratigraphy of the Windsor Group (schematic) showing the regional variations and the relationships of rock units to the major cycles defined in this paper. Formal (uppercase) and informal rock-unit names in current use in Nova Scotia are indicated. The locations of the sections are shown in Figure 1. The vertical scale is distorted for ease of illustration in this figure. For the true vertical scale of Section 3, see Figure 3.

A similar procedure can be reasonably applied in areas where the Windsor succession is truncated by erosion, in which case the resultant unconformity or disconformity forms a convenient upper boundary.

Formal subdivisions of the Windsor Group have not yet been fully defined at the formational level, despite a fifty-year history of stratigraphic study. Figure 2 summarizes the stratigraphic nomenclature in current use. Informal names are indicated only in those areas where research in progress is expected to result in formal definitions in the near future. A brief description of each formation present in the writer's area of principal research (Section 3, Fig. 2) is presented in subsequent pages, followed by a discussion of regional variation in correlative rock units.

## Subdivisions of the Windsor Group

### MACUMBER FORMATION

The Macumber, defined by Weeks (1948), is widely distributed in Atlantic Canada and has been the subject of detailed study by Schenk (1967a, b, 1975). Informal names applied to this rock unit include the "$A_1$ limestone", the "ribbon" limestone, and simply the "basal laminite" (Stacey, 1953; Sage, 1954; Kirkham, 1978; Geldsetzer, 1977, 1978; and others).

Ranging in total thickness from 3 to 18 m, the Macumber is typified by its ubiquitous laminations and by its peloidal character. Laminae comprise couplets of peloidal and micritic limestone. Inverse grading is common in the peloidal layers (Schenk, 1967a, b). Fossils are rare. Moulds of anhydrite or gypsum crystals occur near the top of the Macumber (Geldsetzer, 1978). Bituminous material is a common constituent of the Macumber Formation in core samples from the central part of the Shubenacadie Basin (Section 3, Figs. 1 and 2).

### PEMBROKE BRECCIA

Weeks (1948) applied the name Pembroke Formation to a limestone breccia with associated calcareous sandstones and mudstones, which overlies the Macumber Formation at numerous localities in central Nova Scotia. Clifton (1967) believed the breccia to be of solution-collapse origin formed long after deposition of the Windsor Group, as did Geldsetzer (1978). Clifton recommended that the term Pembroke be abandoned as a formal lithostratigraphic term in Nova Scotia. The age of the Pembroke breccia is a matter of some dispute (e.g. Geldsetzer, 1977, 1978) and may prove to be of critical importance in reconstructing the tectonic (and paleogeographic) history of the Windsor Group. However, since neither the age nor the origin of the Pembroke breccia is critical to the concepts presented in this paper, it has not been described in detail.

### GAYS RIVER FORMATION

First used informally by Boehner (1977), the term Gays River Formation is applied to a thin (3 m) sparsely fossiliferous, argillaceous

and bituminous dolostone which occurs at the base of the Windsor Group in the southern part of the Shubenacadie Basin and in the Musquodoboit Basin (Sections 2 and 3, Figs. 1 and 2). Locally, complex carbonate mounds are present on paleotopographic highs. These mounds contain a varied fauna consisting of brachiopods, molluscs, tabulate corals, and bryozoans (Ryan, 1978). Blue-green, Codiacean and Dasycladacean algae are common mound constituents, and often dominate the biota (Giles et al., 1979).

Rocks similar to those of the Gays River Formation have been noted in the Mahone Bay area, and in parts of the Stellarton Gap area, the Antigonish Basin, and southeastern Cape Breton Island (Fig. 2). Lateral equivalence of the Macumber and Gays River Formations can be demonstrated in the Shubenacadie Basin (Giles et al., 1979) and has been generally accepted as a facies concept throughout Nova Scotia (Hatt, 1978; Ryan, 1978; Geldsetzer, 1977, 1978; Kirkham, 1978). Schenk (1967b) was first to suggest the lateral relationships, but believed that the carbonate mounds were deposited basinward and downslope from the Macumber Formation laminites. Geldsetzer (1978) believed that the converse relationship existed where paleotopographic relationships could be determined. Giles et al, (1979) reported the Macumber Formation to lie downslope from the typical Gays River Formation, thus supporting Geldsetzer's belief.

## CARROLLS CORNER FORMATION

Second only to the Macumber Formation in regional extent, the Carrolls Corner Formation (Giles and Boehner, 1979; Fig. 2), consists mainly of anhydrite and gypsum in deposits reaching 350 m in thickness. Termed the Lower Sulphate Bed by Weeks (1948), this thick evaporite unit is typified by its massive and uniform character, broken in vertical succession only by the occasional presence of laminated anhydrite in short intervals, and by sporadically intercalated beds of laminated dolostone 1 to 2 m in thickness. In its upper parts, the Carrolls Corner Formation includes gypsum and siltstone in a zone of hydration reaching 100 m in thickness. The Carrolls Corner is typically concordant and conformable with the underlying Macumber Formation, except where the Pembroke breccia is present.

In the Windsor area (Section 4, Fig. 2), the White Quarry Formation (new name, formal definition in preparation) equates in its lower parts with the anhydrite of the Carrolls Corner Formation. In the Stellarton Gap area, however, the correlative Bridgeville Formation comprises thinly interstratified anhydrite and limestone. varying in vertical succession to relatively pure anhydrite lacking carbonate interbeds.

## MEAGHERS GRANT FORMATION

The Meaghers Grant Formation (Boehner, 1977; Giles and Boehner, 1979) is found in the southern parts of the Musquodoboit Basin (Section 2, Figs. 1 and 2) where it rests upon carbonate rocks of the Gays River Formation. Grey sandstones and shales characterize the Meaghers Grant. Thin oolitic and stromatolitic carbonate rocks are intercalated, and

northwards and upwards transition with the Carrolls Corner Formation is indicated by the presence of tongues of anhydrite within and above this terrigenous succession. Boehner (1977) suggested a marine tidal-flat and/or a deltaic origin for the Meaghers Grant.

Equivalents of the Meaghers Grant Formation include an unnamed sequence of sandstones and shales in parts of southeastern Cape Breton Island (Section 14, Figs. 1 and 2), and shales reported in water well records in the Mahone Bay area (Section 1, Figs. 1 and 2) of southern mainland Nova Scotia. Fine grained red and grey mudstones which occupy a similar stratigraphic position in the western Antigonish Basin (Section 9, Fig. 2), may be correlative, but are not yet fully understood and may, in fact, be marginal facies of younger Windsor strata.

STEWIACKE FORMATION

In the Shubenacadie Basin (Section 3, Figs. 1 and 2), the Carrolls Corner Formation underlies and in its upper parts is probably laterally equivalent to halite in deposits reaching 300 m in thickness. Termed the Stewiacke Formation (Giles and Boehner, 1979), this major rock unit consists of banded and massive halite at the base, overlain by halite with thin intervals of anhydrite, passing upwards in turn to interstratified halite and siltstone. Very locally, red siltstone containing angular to subangular clasts of laminated anhydrite rests upon halite of the Stewiacke Formation. This siltstone-anhydrite breccia, which reaches 60 m in thickness, is included within the Stewiacke Formation, but may be correlative with the Tennycape Formation (see below). The Stewiacke Formation correlates lithostratigraphically with the upper part of the White Quarry Formation in the Windsor area (Section 4, Figs. 1 and 2).

TENNYCAPE FORMATION

In the Walton-Tennycape area (Section 5, Figs. 1 and 2), Weeks (1948) defined the Tennycape Formation as a succession of fine grained red-brown sandstone and siltstone resting upon the Lower Sulphate Bed (Carrolls Corner Formation correlative) or upon the Pembroke breccia where the Lower Sulphate Bed is not represented. Weeks (1948) reported a thickness of approximately 200 m for the Tennycape Formation at its type locality.

Moore and Ryan (1976) believed that, in complete sections, the Tennycape should lie upon halite of the upper White Quarry Formation in the type area of the Windsor Group. This interpretation is consistent with observations in the Shubenacadie Basin where Stewiacke Formation halite contains increasing intercalated red and greenish-grey siltstone towards the top, and is locally capped by anhydrite-cobble breccia with a red siltstone matrix.

In its type area, the Tennycape is reported to be overlain by a second (higher) sulphate bed (Weeks, 1948). Weeks (1948) stated that the Tennycape was overlain by grey limestone without intervening sulphate at one locality. These rocks are here provisionally equated with evaporites and limestone respectively of the MacDonald Road Formation (see next

heading). The nature of the contact is unknown, but is tentatively interpreted as a disconformity or unconformity (Fig. 2). This conclusion is based mainly on regional variation in juxtaposed rock units at the lower contact of the MacDonald Road Formation. Data pertaining to the age and stratigraphic position of the Tennycape Formation are admittedly few. The relationship between the Tennycape Formation and the Pembroke breccia, in particular, requires more research.

In the Antigonish Basin and parts of Cape Breton Island (Fig. 2), fine grained red-brown siltstones (?Tennycape equivalent) overlie major salt deposits which may be correlated with those of the Stewiacke Formation. Stratigraphic relationships in the lower parts of the Windsor Group in each of these areas are not yet fully understood, but are here presumed to be similar to those postulated in south-central Nova Scotia.

MACDONALD ROAD FORMATION

The term MacDonald Road Formation (Giles and Boehner, 1979), was applied in the Shubenacadie Basin (Section 3, Figs. 1 and 2), to a complex succession of rhythmically alternating evaporites, carbonate rocks, and fine grained terrigenous rocks reaching 185 m in thickness (Fig. 3). Gypsum and anhydrite predominate, with lesser fossiliferous marine limestone and dolostone. Red-brown siltstone becomes increasingly common towards the top. In the Musquodoboit Basin (Section 2, Figs. 1 and 2), the Formation lacks evaporitic rocks, and is characterized by subequal proportions of carbonate rocks and medium- to coarse-grained terrigenous rocks. In the Windsor area, strata correlative with the MacDonald Road Formation are assigned by R. G. Moore (research in progess, Acadia University) to the Miller Creek and Wentworth Station Formations, and are similar to strata found in the Shubenacadie Basin. Schenk (1969) described stratigraphically equivalent rocks in the lower parts of the Monks Head and Port Hood Island successions (Sections 11 and 12 respectively, Fig. 2). Crowell (1972) recognized MacDonald Road equivalent strata in the Loch Lomond area of southeastern Cape Breton Island (Section 15, Fig. 2), where the intercalated terrigenous rocks are commonly conglomeratic. Rocks correlative with the MacDonald Road Formation in the Loch Lomond area rest directly on pre-Carboniferous rocks, as they do in the northern part of the Stellarton Gap area (Section 7, Fig. 2).

R. G. Moore (personal communication, 1980) believes that thin carbonate beds within the Miller Creek and Wentworth Station Formations are, to varying degrees, lithologically distinct and laterally continuous over large areas. The writer's study of the MacDonald Road Formation in the Shubenacadie Basin and study of the same Formation in the Musquodoboit Basin (Boehner, 1977), clearly establish the value of the carbonate members for lithostratigraphic correlation.

Significant lateral variation within strata thought to be equivalent to the MacDonald Road Formation exists in the western parts of the Antigonish Basin (Section 9, Fig. 2), where evaporites are subordinate and carbonate marker beds are thin or absent. In this area, no clear lithostratigraphic distinction has yet been noted between fine grained terrigenous rocks possibly equivalent to the Stewiacke, Tennycape, and MacDonald Road Formations.

## GREEN OAKS FORMATION

Named by Giles and Boehner (1979), the Green Oaks Formation is dominated by red-brown siltstone (and sandstone) with lesser intercalated carbonate rocks and evaporites (Fig. 2). The base of the Formation is placed at the base of the Herbert River Limestone Member of Moore (1967), the correlatives of which can be recognized throughout Nova Scotia. Although broadly similar to the MacDonald Road Formation, the Green Oaks differs in that terrigenous rocks predominate, evaporites are typically subordinate or absent, and the carbonate members are characterized by the presence of well-developed, near normal marine, subtidal lithotopes in addition to marginal marine lithotopes recording both transgression and regression. The documented thickness of the Green Oaks Formation (and equivalents) ranges from 185 to 300 m.

Moore (1967) described and named seven carbonate members in the upper part of the Windsor Group in the Windsor area and in the northern part of the Shubenacadie Basin. These members are assigned here to the Murphy Road Formation (new name) in the Windsor area and to the Green Oaks Formation in the Shubenacadie Basin. Schenk (1969) described equivalent strata in the Port Hood Island section (Section 12, Fig. 2). Less detailed descriptions were given by Stacey (1953) and Sage (1954).

Lateral continuity of carbonate members within the Green Oaks Formation can be demonstrated (Fig. 2) and strongly supports Moore's (1967) assertion that lithologic characteristics enable the recognition of discrete carbonate members over large areas. Facies variation, however, is significant on a regional basis, and care must be taken in member-for-member correlation between widely separated structural basins.

The Green Oaks Formation normally rests upon rocks equivalent to the MacDonald Road Formation. Keppie et al. (1978) showed that rocks equivalent to the Green Oaks Formation rest directly upon pre-Carboniferous rocks near Knoydart Point (Section 8, Fig. 2). The writer has been unable to confirm similar relationships elsewhere in Nova Scotia, although the northern part of the Stellarton Gap area (Section 6, Fig. 2) shows only a thin veneer of conglomerate beneath the Hebert River Limestone correlative to which no formal name has been applied.

## WATERING BROOK FORMATION

Above the highest marine carbonate unit in the Shubenacadie Basin, but conformable with that carbonate, lies a succession of grey and red siltstone and mudstone with associated gypsum, anhydrite and minor halite. These rocks have been assigned to the Watering Brook Formation (Giles and Boehner, 1979) and are here provisionally included within the Canso Group (Fig. 2). In the Windsor area, similar rocks in this stratigraphic position are considered an upper part of the Murphy Road Formation and are included within the Windsor Group (R. G. Moore, personal communication, 1979). The boundary between the Windsor and Canso Groups, shown in Figure 2, illustrates this variation in definition.

## MAJOR TRANSGRESSIVE-REGRESSIVE CYCLES

Ramsbottom (1973) recognized six major cycles in the British Dinantian, each characterized by transgressive and regressive phases recognized by changes in lithology and fauna. Rhythmic sedimentation throughout the middle and upper parts of the Windsor Group produced by alternating transgression and regression, and a well established biostratigraphic framework, suggested to the author that similar cycles could be recognized in Nova Scotia. An initial attempt has been reported (Giles, 1978) in which three major cycles were proposed. The youngest of these was subsequently subdivided yielding a total of five cycles (Giles, 1979a). In this paper, the writer defines these five cycles, based upon the complete and tectonically little disturbed Shubenacadie Basin succession. The regional assignment of both formal and informal lithostratigraphic units of the Windsor Group (and in part the Canso Group) to each of the cycles is shown in Figure 2.

### Definition of the Cycles

#### MAJOR CYCLE 1

The earliest Visean marine invasion of Atlantic Canada is recorded in Nova Scotia by fossiliferous strata of the Gays River Formation, or its lateral equivalent, the Macumber Formation. The base of these Formations marks the base of Cycle 1. At certain rare localities, thin and erratically distributed sandstone and conglomerate, or breccia beds of possible marine origin may lie beneath these Formations (Bell, 1929, 1958) and locally may be considered the basal deposits of Cycle 1. Also assigned to Cycle 1 are the Carrolls Corner, White Quarry, Stewiacke, Meaghers Grant and Tennycape Formations (Fig. 2). With the exception of the Meaghers Grant Formation (basin margin facies), these rock units reflect a trend towards increasingly saline deposition culminating in arid-flat sedimentation and subaerial exposure (Giles and Boehner, 1979), as indicated by the vertical sequence carbonate, anhydrite, halite, red siltstone.

Cycle 1 coincides approximately with the A faunal subzone of Bell (1929). A marine fauna of 28 species has been reported from the Macumber and Gays River Formations (Moore and Ryan, 1976; Ryan, 1978; Giles et al., 1979). Mamet (1970) reported scarce plurilocular Foraminifera from carbonate rocks here assigned to the base of Cycle 1, including both the Macumber and Gays River Formations of this paper. Von Bitter and Plint-Geberl (1979) reported conodonts from the Macumber-correlative, the Ship Cove Limestone, in Newfoundland.

#### MAJOR CYCLE 2

The earliest marine transgression of Cycle 2 is evidenced by wide-spread deposition of banded, dolomitic, grey and grey-green siltstone which comprises the basal unit of the MacDonald Road Formation in the Shubenacadie Basin. Marine fossils, although present, are rare in the basal silt. It is overlain transitionally by marine limestone or dolostone with associated gypsum and anhydrite. The banded siltstone rests on gypsum (or anhydrite) of the Carrolls Corner Formation, or on halite of the Stewiacke Formation. The boundary between beds included

in Cycle 1 and those included in Cycle 2 is very abrupt, suggesting that the boundary between the two cycles represents a hiatus. Definition of Cycle 2 as a major cycle obscures its composite character (Fig. 3). The definition is justified by a gradual upwards increase in the proportion of terrigenous rocks, and by the marginal marine character of carbonate rocks high in the cycle, compared with highly fossiliferous and thicker carbonate members in the lower parts of the cycle.

Cycle 2 coincides approximately with macrofaunal subzone B of Bell (1929; Fig. 3), and its base approximates but does not precisely coincide with Bells subzone A-B boundary. Utting (1978) reported little change in miospore assemblage at the subzone A-subzone B boundary.

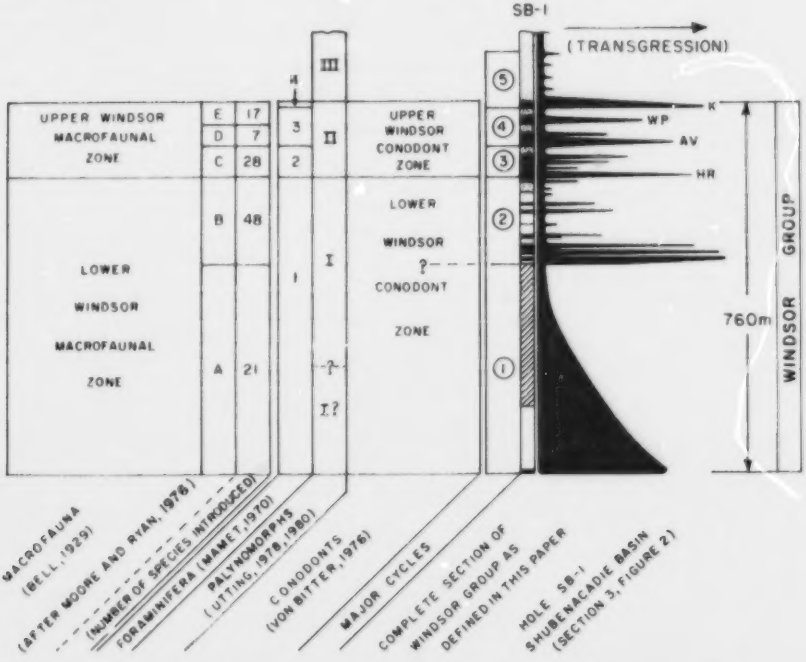



Figure 3. Biostratigraphy, lithostratigraphy and major depositional cycles in the Windsor Group. The section illustrated is generalized from borehole SB-1, Shubenacadie Basin, drawn to scale as indicated. Note the change in cycle character at the Cycle 1-Cycle 2 boundary. Carbonate members cited in the text and/or those introducing significant numbers of new faunal elements are emphasized for the sake of illustration. K = Kennetcook Limestone Member; WP = Wallace Point Limestone Member; AV = Avon Limestone Member; HR = Herbert River Limestone Member.

Similar conclusions were reached by von Bitter (1976) in studies of conodont assemblages (Fig. 3). In the Windsor-equivalent Codroy Group of Newfoundland, von Bitter and Plint-Geberl (in press) found a sharp conodont zone boundary separating the Fishels Limestone from underlying rock units. This boundary presumably corresponds to the Cycle 1-Cycle 2 boundary of this paper (von Bitter, written communication, 1980). Mamet (1970) reported a change in Foraminifera population across this boundary, but believed that the lower population was an impoverished equivalent of the upper, and thus included both within a single assemblage-zone.

MAJOR CYCLE 3

The base of Major Cycle 3 is defined as the base of the Herbert River Limestone Member of Moore (1967). It thus coincides by definition with the base of the Green Oaks Formation in the Shubenacadie Basin. Four transgressive marine pulses are known in Cycle 3, and are typically recorded in the lower two-thirds of the cycle. The upper one-third of the cycle consists largely of red-brown siltstone, with very minor gypsum or anhydrite. Each transgressive pulse in Cycles 3, 4, and 5 is represented by a minor depositional cycle. Beginning with the earliest record of marine transgression, these minor cycles can be generalized in ascending order to include deposition of green siltstone, marginal marine carbonates, subtidal carbonates, marginal marine carbonates, anhydrite, and red siltstone. The position of the latter rock type within the cycles clearly suggests a continental or high supratidal-flat origin for the redbeds.

The base of Cycle 3 coincides with a major biostratigraphic boundary defined by changes in assemblages of macrofaunal elements, conodonts, calcareous Foraminifera, and miospores (Fig. 3). This correspondence of microfaunal and macrofaunal zone boundaries appears likely to represent a chronostratigraphic gap (Mamet, 1970), suggesting that the Cycle 2-Cycle 3 boundary represents a hiatus in the stratigraphic succession.

MAJOR CYCLE 4

The base of Cycle 4 is placed at the base of a thin (1 to 2 m) silty limestone bed, which occurs beneath the Avon Limestone Member of Moore (1967) and is separated from that member by 1 to 2 m of grey-green siltstone and/or gypsum. This thin limestone appears sedimentologically to represent a minor transgressive pulse related to the ensuing transgression that resulted in the deposition of the Avon Limestone. Additional transgressive pulses within Cycle 4 are represented by the Meander River and Wallace Point Limestone Members, each also defined by Moore (1967). In the Port Hood Island section (Section 12, Fig. 2), the base of Cycle 4 is defined by the base of a thin (< 1 m) unnamed limestone bed a short interval beneath the $C_1$ limestone of Stacey (1953). Additional transgressive pulses are represented by the $C_2$, $C_3$, $D_1$, $D_2$ and $D_3$ limestones. The implied correlation of the Avon Limestone with the $C_1$ limestone is here suggested for the first time and is based largely on the first appearance of *Martinia galataea* (Stacey, 1953; Moore and Ryan, 1976).

The base of Cycle 4 approximates, but does not precisely coincide with the C-D macrofaunal subzone boundary which is placed at

the base of the Avon Limestone Member. The cycle crosses the D-E subzone boundary, placed by Bell (1929, p. 53), at the base of "unit (a)", Section 10. That unit was named the Wallace Point Limestone Member by Moore (1967; Fig. 4). Placement of the D-E subzone boundary at that level was questioned by Waring (1967) and Crowell (1968), and data presented by Moore and Ryan (1976) show only one new species appearing in the Wallace Point Limestone compared with sixteen new species in the overlying Kennetcook Limestone (Fig. 4). Moore (1967) observed that the Wallace Point was faunally and lithologically more similar to the Avon and Meander River Limestone Members of the D subzone than it was to the Kennetcook Limestone, and stated that it might better have been included in the D subzone. Thus, its inclusion in Cycle 4 seems justified.

MAJOR CYCLE 5

The base of Cycle 5 is placed at the base of the Kennetcook Limestone Member of Moore (1967) in southern Nova Scotia, and at the base of the $E_1$ limestone in the Port Hood Island section of Stacey (1953). The Kennetcook Limestone is the thickest known member of the Green Oaks Formation. This limestone is often overlain by laminated to massive gypsum or anhydrite in conformable succession, as is the $E_1$ limestone. This anhydrite may be in turn overlain by halite up to 25 m in thickness. Higher in the cycle, grey and red-brown mudstone and siltstone predominates, with minor transgressive (?) pulses indicated by thin gypsum beds, the highest of which defines the top of the cycle. Cycle 5 thus appears to record, in miniature in its lower parts, a sedimentary history similar to that of Cycle 1.

The major biostratigraphic change coincident with the base of Cycle 5 appears to be the addition of sixteen (16) new macrofaunal species to the Windsor fauna at that level (data from Moore and Ryan, 1976). Von Bitter (1976) noted no change in the conodont assemblage coincident with the base of the Kennetcook Limestone, i.e. across the Cycle 4-Cycle 5 boundary of this paper (Fig. 3). Similarly, Utting (1978, 1980) reported no change in miospore assemblages at the base of the Kennetcook Limestone Member. However, significant new miospore species appear above the Kennetcook Member within the Watering Brook Formation (Utting, 1980). As a result, Utting tentatively placed an assemblage-zone boundary (II-III; Fig. 3) at the top of the Kennetcook Limestone. Miospore assemblage-zone III extends at least to the top of the Watering Brook Formation (Utting, 1980). It thus extends above the top of Major Cycle 5 as defined in this paper (Section 3, Fig. 2).

Mamet (1970) noted the appearance of several important taxa of calcareous Foraminifera a short distance above the base of the Kennetcook Limestone Member, and placed an assemblage-zone boundary (3-4, Fig. 3) at that level. This zonal boundary approximates, but does not coincide with, the base of Major Cycle 5.

## TIME SIGNIFICANCE OF THE MAJOR CYCLES

Ramsbottom (1978) ascribed time-significance to major transgressive-regressive cycles of Namurian age in Europe. He attributed these cycles to widespread eustatic changes in sea level. George et al. (1976), in defining new Dinantian stages in Britain, recognized the

approximate equivalence of stage boundaries to major cycle boundaries proposed by Ramsbottom (1973).

Mamet (1970) presented convincing arguments for the time-significance of foraminiferal assemblage-zone boundaries in Nova Scotia and New Brunswick. Von Bitter (1976) believed that the major conodont assemblage-zones reflected biostratigraphic rather than ecologic restrictions, based on the appearance of key genera in varied rock units (and depositional environments). The belief has been strengthened through study of the distribution of Low Codroy Group conodonts of Newfoundland (von Bitter and Plint-Geberl, in press).

Schenk (1967a, b) postulated that the Macumber Formation at the base of Cycle 1 was the product of sudden marine invasion of a Visean sea into the Atlantic region. The base of the Macumber should therefore approximate a time plane. This concept has received support from Geldsetzer (1977, 1978) and Kirkham (1978), and is here accepted in broadened terms to include deposition of the Gays River Formation. Explanations for the sudden marine invasion have been advanced by Geldsetzer (1978) and Kirkham (1978), each of which believed that the Visean sea inundated a broad and complex terrain, largely below sea level. Tectonic breaching of a presumed barrier was invoked by Kirkham (1978) whereas Geldsetzer (1978) acknowledged that eustatic sea level change could also have provided the mechanism for sudden marine invasion across a barrier arch.

The Cycle 2-Cycle 3 boundary affords convincing evidence for time-significance of individual marine limestone members. The Herbert River Limestone Member, the base of which forms the base of Cycle 3, records both marine transgression and subsequent regression, and thus is the product of a discrete depositional event which is time-significant. In ascending vertical profile, the transgressive phase is marked by the sequence: stromatolitic limestone (sometimes absent), ostracodal and intraclastic limestone, silty crinoidal and bioclastic limestone, and bioclastic crinoidal limestone. This sequence then reverses through a silty, bioclastic phase to a stomatolitic limestone which may have been locally developed and/or preserved. Anhydrite completes the regressive sequence in many instances, and exceptionally, halite may appear in the upper parts of the depositional cycle.

At least 28 macrofaunal elements (Fig. 3) were introduced for the first time with this marine invasion according to the data of Moore and Ryan (1976). Some of these elements were environmentally sensitive and tend to occur mainly in a specific lithotype. Others, in particular some rugose coral species, appear regionally in a variety of lithotopes and are useful guide fossils.

Although environments of deposition similar to those of the Herbert River Limestone, repeat in subsequent marine transgressions, faunal elements present in higher limestone members differ. Faunal inversion is not known in the Windsor Group, a fact emphasized by Mamet (1970). Thus, changes in faunal assemblages through time, as represented by vertical stacking of multiple transgressive events, appear to be biologically rather than ecologically controlled.

Lateral variation in limestone members is gradual and is not necessarily expressed in preceeding or subsequent carbonate members. Thus, the lateral changes in any given carbonate member do not prohibit regional correlation based on lithologic criteria alone. Correlations established in this manner, when combined with biostratigraphic data, have shown that selected macrofaunal elements can be applied on a regional basis as guides to stratigraphic position (Moore, 1967; Moore and Ryan, 1976).

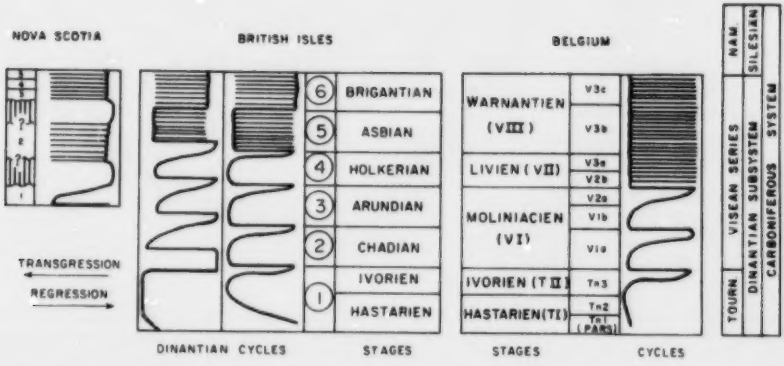
Figure 3 shows clearly that the Herbert River Limestone represents only one of at least eighteen broadly similar transgressive-regressive sheet-like carbonate members within the Green Oaks and MacDonald Road Formations. Not all transgressive pulses introduced significant members of new faunal elements, but each records a distinct event (transgression-regression), separated in time from earlier and later transgressions. Thus, each thin carbonate sheet of Cycles 2 to 5 approximates a time marker, as well as a lithostratigraphic marker, within the Windsor Group.

## CORRELATION WITH MAJOR CYCLES AND STAGES IN THE DINANTIAN OF BRITAIN

Ramsbottom (1973) suggested that the six major cycles of transgression and regression which he defined in the Dinantian of Britain (Fig. 4), could be recognized in Belgium and in the United States in strata of Visean and Mississippian age respectively. Groessens (1974) intimated that the major cyclicity in Dinantian and Visean strata of Britain and Belgium could be extended on an intercontinental scale. George et al. (1976) combined lithostratigraphic and biostratigraphic data to postulate correlation of their newly defined Dinantian stages (Fig. 4), with lower Carboniferous and Mississippian successions in Belgium and the United States, respectively. If these authors are correct, then it should be equally possible to recognize equivalent major subdivisions in the Windsor Group of Atlantic Canada.

Ramsbottom's (1973) major cycles (Fig. 4) coincide approximately with the six Dinantian stages for which the pertinent biostratigraphic data are summarized (George et al., 1976). In subsequent paragraphs, the Dinantian stage names are applied. Figure 4 summarizes the correlations postulated here.

MAJOR CYCLE 1: Because biostratigraphic data for Cycle 1 (subzone A) of the Windsor Group are not yet complete, the age of the cycle is uncertain. Macrofaunal data for subzone A (Ryan, 1978; Moore and Ryan, 1976; Giles et al., 1979) reveal a high degree of similarity to faunal lists for subzone B (Cycle 2) (Bell, 1929; Moore and Ryan, 1976). The major difference in these respective faunas is a noticeable restriction in species numbers in subzone A (Cycle 1). It is perhaps significant that *Koninckopora* is abundant in rocks of Cycle 1, specifically in carbonate mounds of the Gays River Formation (Giles et al., 1979). This Dascycladacean is abundant in the Arundian stage in Britain (George et al., 1976) and appears first in the Late Moliniacian ($V_2a$, Mamet and Skipp, 1970) in Belgium (Fig. 4). However, because the vertical distribution of *Koninckopora* extends above the Arundian, an age younger than Arundian cannot be precluded.




AFTER RAMSBOTTOM (1973), GEORGE ET AL. (1976), CONIL AND LYS (1977), AND RAMSBOTTOM AND MITCHELL (1980)

Figure 4. Comparison and tentative correlation of transgressive-regressive cycles in the Dinantian of Belgium and Britain with the major cycles in the Windsor Group of Nova Scotia. Note the correspondence of British stages to the Dinantian cycles of Ramsbottom (1973). Vertically ruled areas indicate possible breaks in the stratigraphic record produced by subaerial erosion during regressive maxima. Small-scale cyclicity in Nova Scotia is shown as largely regressive with small transgressive pulses. This contrasts with Belgium, where small-scale cyclicity is defined by regressive pulses in a regionally transgressive situation. Note that small scale sedimentary rhythms appear earlier in Belgium (and in Nova Scotia?) than in the British Isles.

Mamet (1970) believed that no time-significant biostratigraphic distinction could be made between Foraminifera of subzones A and B (Cycles 1 and 2 respectively in this paper), and thus assigned Foraminifera from both subzones to his assemblage-zone 1 (Fig. 3). Nevertheless, Mamet (1970) noted differences between the faunas of subzones A and B. With further study, these respective faunas may be found to be biostratigraphically distinct.

Von Bitter and Plint-Geberl (1979 and in press) reported a diagnostic conodont fauna in the lower Ship Cove Limestone, the stratigraphic correlative in Newfoundland of the Macumber and Gays River Formations. Because of the apparent restriction of this fauna to Eastern Canada, no assessment of age was possible. They reported a conodont zone boundary at the top of the thick sulphate which overlies the Ship Cove Limestone. This boundary should equate with the Cycle 1-Cycle 2 boundary of the present paper.

Utting (1980) has studied miospores in a single, complete section of the Windsor Group in the Shubenacadie Basin (section 3, Fig. 2). Miospores from rocks of both subzones A and B were assigned by Utting to assemblage-zone I (Fig. 3) with a cautionary note that subdivision of the zone might be justified by further research. The top of Utting's assemblage-zone I does not, however, coincide with the Cycle 1-Cycle 2 boundary defined in this paper. Thus Utting's assignment of an Arundian to possibly Holkerian age to his assemblage-zone I seems to apply equally to rocks of both Cycles 1 and 2 (subzones A and B, respectively).

MAJOR CYCLE 2: Two-layered Palaeotextulariids appear in rocks of Cycle 2 (B subzone, Mamet, 1970) and at the base of the Holkerian stage in Britain, indicating that the base of Cycle 2 should be Holkerian in age or younger. The first recorded appearance of the conodont *Gnathodus bilineatus* in the Windsor Group is in the Herbert River Limestone Member (von Bitter, 1976, p. 239) at the base of Cycle 3. This conodont species, which first appears is the Asbian stage in Britain (George et al., 1976, p. 11), has more recently been recovered from rocks here assigned to Cycle 2 in the Windsor type area (P. H. von Bitter, written communication, 1980). The presence of *Gnathodus bilineatus* in rocks of Cycle 2 suggests that the Cycle extends in time into the Asbian (Fig. 4). Thus the interpretation based on conodonts is in partial accord with that of Mamet (1970) who believed that calcareous Forminifera of the B subzone (Cycle 2) were equivalent to those reported from the $V_3b$ of Belgium (Fig. 4) thereby equating them with Asbian forms in Britain. On the other hand, Utting (1980) suggested that his assemblage-zone I was probably not younger than Holkerian in age. This conclusion would place a pre-Asbian age on rocks of Cycle 2. In view of these differing interpretations both the lower and upper boundaries of Cycle 2 must be considered very tentative (Fig. 4).

MAJOR CYCLE 3: The base of Cycle 3, which is also the base of subzone C of Bell (1929), is marked by the appearance of the first *Neoarchaediscus*, (Mamet, 1970), considered by George et al., (1976) to be a guide fossil to the Brigantian stage. *Asteroarchaediscus* also is reported from lowermost C subzone limestone at Mamet's locality 82263, previously assigned to subzone E (Sage, 1954) but now known to contain C subzone rugose corals (Moore, personal communication, 1978). *Asteroarchaediscus* is considered, like *Neoarchaediscus*, to be characteristic of the Brigantian by George et al. (1976). The Brigantian correlates with the uppermost $V_3b$ and $V_3c$ of the Belgium succession (George et al., 1976). The placing of the base of Cycle 3 within the Brigantian is in accord with Mamet's interpretation of international correlation of the base of foraminiferal assemblage-zone 3 (Mamet, 1970, p. 15-18).

Macrofaunal evidence for placing the base of Cycle 3 at the level of the Brigantian stage, rests mainly on the reported presence of the rugose coral *Lonsdaleia floriformis* in the Herbert River Limestone Member (Giles, 1979b). This species is also reported from the Musquodoboit Limestone Member (Moore and Ryan, 1976), considered to be correlative with the Herbert River Limestone by Boehner (1977) and Moore and Austin (1979). *Lonsdaleia floriformis* is considered a definite guide to the Brigantian by George et al. (1976). Adams (1978) concluded that giganto-

productids of the Herbert River and Musquodoboit Limestone Members of the C subzone in Nova Scotia, appeared in Britain at the $D_1$-$D_2$ boundary. George et al. (1976) equated the latter boundary with the Asbian-Brigantian boundary.

Among the conodonts reported (von Bitter, 1976) in rocks of Cycle 3, *Gnathodus bilineatus* and *Gnathodus girtyi intermedius* seem most significant. *G. bilineatus*, appears in the Asbian in Britain (George et al., 1976). *G. girtyi* appears at a higher level within the Late Visean, but, like *G. bilineatus*, also extends into the Namurian in Belgium (Groessens, 1974). Thus together, they constitute proof that the base of Cycle 3 must be Asbian, or younger.

Utting (1978, 1980) noted the appearance of important new miospores at the subzone B-subzone C boundary, and designated the upper population assemblage-zone II. He tentatively assigned a Late Visean Asbian age to this assemblage-zone based upon the appearance of *Grandispora spinosa* in his assemblage-zone III. *Grandispora spinosa* first appears in the Brigantian of Britain (Utting, 1980). The writer has weighted combined macrofaunal and foraminiferal data over the palynological evidence in reassigning Utting's zone II to the Brigantian.

MAJOR CYCLE 4: Present biostratigraphic data do not permit an independent assessment of age for Cycle 4. The age postulated for Cycle 3 establishes a Brigantian or younger age for Cycle 4. The age of Cycle 5 (see below) provides age limits at the top of Cycle 4.

MAJOR CYCLE 5: The top of the Brigantian stage in Britain marks the first appearance of Namurian faunas (George et al., 1976). The highest marine fossils in the Windsor Group occur in the Kennetcook Limestone Member, the base of which forms the base of Major Cycle 5 as defined in this paper. Bell (1929) assigned the uppermost Windsor macrofauna to the Late Visean. He subsequently postulated that the lowest Canso strata were also of Late Visean age (Bell, 1958). Lewis (1935) who studied rugose corals from Cycles 3 and 5 as defined in this paper concluded that the corals were indicative of Late Visean age.

Neves and Belt (1970) concluded that the Windsor Group was entirely Visean in age, and that the Visean-Namurian boundary, as defined by palynomorphs, occurred in the upper parts of the Hastings Formation of the Canso Group. The lower part of the Hastings Formation, which contains palynomorph assemblages very similar to those of the Watering Brook Formation (Utting, 1980), was also considered to be of Visean age. Evidence critical to this interpretation is the appearance of the species *Potonieisporites elegans* in the upper Hastings Formation (Neves and Belt, 1970). Clayton et al. (1977) reported the appearance of *P. elegans* at the base of the $E_1$ goniatite zone (basal Namurian) in England, thus supporting the emphasis placed upon this species by Neves and Belt.

Utting (1980) concluded that miospores recovered from strata of the Watering Brook Formation, and from strata in similar stratigraphic position in the Lake Enon area of southeastern Cape Breton, were Visean in age, thus limiting the Windsor Group to the Visean. Utting (1980)

suggested that the base of his assemblage-zone III (Fig. 3) may mark the base of the Brigantian. The writer has emphasized the macrofaunal and foraminiferal data in lowering the base of the Brigantian equivalent in Nova Scotia to the base of Cycle 3 (Fig. 4).

Mamet (1970) reported earliest Namurian Foraminifera from the Kennetcook Limestone Member, slightly above its base. The taxa *Asteroarchaediscus baschkiricus* and *Endothyranopsis sphaerica* were cited by Mamet (1970, p. 17) as indicators of Namurian age, but were also cited by George et al. (1976, p. 75) as taxa typical of the Brigantian (pre-Namurian).

Globensky (1967) believed that conodonts from the upper part of the Windsor Group indicated an early Namurian age for the youngest Windsor strata. However, P. H. von Bitter (personal communication, 1979) has pointed out that many important conodont taxa range across the Visean-Namurian boundary, and cannot therefore be used to rigorously locate the top of the Visean.

The weight of evidence thus seems to indicate that Cycle 5 lies wholly within the Late Visean, i.e. the Brigantian of George et al. (1976).

## ORIGIN OF THE CYCLES

Rhythmic sedimentation in the Windsor Group was attributed by Bell (1929, p. 56) to climatic or tectonic oscillation under generally semiarid conditions. Fossiliferous limestones were deposited during episodes of free communication with the outside sea. Evaporite deposition occurred under conditions of elevated temperatures at high salinity. Red shales were presumed to be mainly of marine origin although possibly in part of continental origin (Bell, 1929, p. 84). The absence of fossils in the shales was attributed to muddiness of water and high temperatures (Bell, 1929, p. 55). Bell did not apparently consider the possibility of rhythmic changes in sea level, perhaps because of his belief that <u>all</u> Windsor strata were of probable shallow marine origin.

Moore (1967) recognized that carbonate members in the upper part of the Windsor Group were the deposits of marine transgression followed by regression. Sedimentation was controlled mainly by tectonism which included differential, but gradual subsidence of a trough and by climatic fluctuation (Moore, 1967, p. 265). Under conditions of continuous subsidence, cessation of silt influx would result in marine transgression with ensuing carbonate deposition. Regression resulted in some cases from basin uplift, but in other cases was caused by terrigenous influx resulting from climatic change and/or distant tectonic uplift (Moore, 1967, p. 264).

Schenk (1969, p. 1063) believed that the mechanism that produced cyclic sedimentation was probably fluctuation in supply of terrigenous detritus into a continuously subsiding basin. He noted, however, that the origin of Windsor Group cycles could not be divorced from Carboniferous cycles in North America or Europe. Schenk briefly considered glacio-eustatic fluctuations in world-wide sea level as a causative mechanism,

but felt that a) proof of continental glaciation of appropriate age was lacking, and b) that validation of precise age equivalence would be required and could be accomplished only by very detailed intercontinental comparison of a finely divided zonation scheme (Schenk, 1969, p. 1062).

Ramsbottom (1973, 1977, 1978, 1979) has stressed that major transgressive-regressive cycles or mesothems in Dinantian and Namurian rocks in Britain were controlled by eustatic sea level changes, citing as his principal argument, the ability to recognize similar major cycles in western Europe and in the United States. The major cycles defined in this paper appear to confirm a very broad distribution of similar phenomena and their correlation provides a possible link between the United States and Europe. Recent arguments for the existence of a major ocean basin between eastern North America and Europe in Visean time (Jansa et al., 1978; Jansa and Mamet, 1979) make the provision of such a link fundamental to Ramsbottom's eustatic hypothesis.

Bott and Johnson (1967), who argued strongly against eustatic control over Carboniferous cyclic sedimentation, proposed that eustatic control should be evidenced by strong erosion between cycles in areas marginal to the sedimentary basins. They argued that evidence was lacking for such erosion in Carboniferous cyclothems in both Britain and the United States. Furthermore, they believed that a suitable mechanism to produce repeated eustatic movements in Carboniferous time was not present.

In view of more current work, the absence of a suitable mechanism for repeated eustatic change in sea level can no longer be considered a valid argument. Donovan and Jones (1979) and Hsu and Winterer (1980) argued convincingly that relatively rapid transgressions and regressions can be caused by either changes in the volume of land ice, or by desiccation of large isolated ocean basins such as the Mediterranean (Hsu, 1972) in Mesozoic time. Crowell (1978) presented evidence for Visean continental glaciations in South America and believed these to represent the earliest glacial events of a 90 million year ice age ending in Early Permian time. Thus, glacio-eustatic sea level change appears possible throughout much of Carboniferous time.

Dramatic physical evidence for repeated periods of subaerial exposure and erosion in British shelf carbonate sequences has been presented by Ramsbottom (1973, 1977, 1978, 1979), Walkden (1974) and Somerville (1979). Giles and Boehner (1979) showed that minor transgressive pulses of Cycle 2 in the Musquodoboit Basin (Section 2, Fig. 2) were separated by erosional intervals, whereas deposition continued without apparent hiatus in the equivalent succession in the Shubenacadie Basin to the north. Thus, the condition specified by Bott and Johnson (1967) seems to be met in central mainland Nova Scotia and in Britain in Late Visean time.

The key to determining the possibility of eustatic control of Visean sea level changes may lie in the future correlation of minor transgressive-regressive pulses characteristic of Ramsbottom's (1973) Cycle 6, with those of Cycles 3, 4, and 5 in the Windsor Group. The strata thus considered are believed to be equivalent in age to the

Brigantian Stage of George et al. (1976). Such a correlation will involve detailed paleontological studies beyond the scope of this paper. Calcareous Foraminifera appear suitable for such correlation, since certain groups evolved rapidly during the Late Visean (Mamet, 1970).

Before such a correlation can be attempted on an international scale, much detailed lithostratigraphic and paleontologic research must be completed both in Britain where uncertainties remain in tracing minor cycles (Walkden, 1979), and in Nova Scotia.

In addition, the role of both local and regional tectonic movements in controlling sea level changes within the Fundy Aulacogene (Keppie, 1977) must be determined. Present data indicate that the carbonate sheets which record marine invasion of the Aulacogene can be traced throughout much of Nova Scotia *in spite of* local variations produced by tectonic effects.

## SUMMARY AND CONCLUSIONS

Lithostratigraphic subdivisions of the Windsor Group can be assigned to five major transgressive-regressive cycles. Cycle 1 comprises a single, rapid marine invasion, followed by slow regression, accompanied by extensive deposition of marine evaporites, and culminating in deposition of fine grained terrigenous clastic rocks. Cycle 2 is characterized by multiple transgressive pulses, each similar in nature, but not in scale to the transgression of Cycle 1. Evaporite deposition is also regionally characteristic of Cycle 2. Cycles 3 and 4 comprise groups of minor transgressive-regressive pulses. Regressive phases are largely dominated by fine grained terrigenous rocks with subordinate evaporite deposits. Cycle 5 is represented by a single marine invasion followed by regression and evaporite deposition. Minor transgressive pulses occur within the general regression which terminates the cycle.

Each of the major marine transgressions used to define the cycle boundaries, brought with it certain faunal elements characteristic of that transgression. Thus, the lithostratigraphic and biostratigraphic boundaries defined by macrofaunal elements, conodonts and Foraminifera, coincide reasonably with major cycle boundaries. Biologic rather than ecologic factors appear to control vertical variations in these faunas. The cycle boundaries appear, therefore, to be time-significant. The parallel and largely coincident position of miospore assemblage-zone boundaries supports this conclusion.

Minor transgressive-regressive pulses within the major cycles represent discrete events of short duration. Recognition of successive minor transgressive events using lithologic and biostratigraphic criteria, provides a level of chronostratigraphic control even more precise than that provided by the major cycles. This level of discrimination may be beyond the resolving power of most biostratigraphic zonations.

Relative to the British stages, Cycle 1 may be equivalent to the Arundian in age or younger, i.e. early Holkerian. Cycle 2 appears to be Holkerian in age, possibly extending into the Asbian. Cycles 3, 4, and 5 are Brigantian in age. A significant hiatus is suggested

between Cycles 2 and 3. The presence of such a hiatus is consistent with the recorded coincident changes in all faunal and floral groups across this boundary.

The five cycles defined in this paper provide a convenient, time-significant framework within which paleogeographic sedimentologic and metallogenic models can be erected. They will, in time, be more fully understood throughout Atlantic Canada, and may provide some guidance in the definition of formal stages. In the meantime, the cycles, along with the available biostratigraphic data, provide subdivisions which are useful for purposes of correlation with areas far removed from Nova Scotia.

The definition of major depositional cycles permits the recognition of a major stratigraphic and sedimentologic break within the lower part of the Windsor Group (Cycle 1-Cycle 2 boundary). This break is not indicated by biostratigraphic zonations using microfauna, Foraminifera or miospores at present, and becomes apparent mainly through an appreciation of rock units and their regional distribution. Conodont zonations may, however, reveal this significant boundary (von Bitter and Plint-Geberl, in press).

On the other hand, the biostratigraphic data indicate a possible hiatus between Cycles 2 and 3 which is not indicated by major differences in cycle character. Thus, the necessity for a combined lithostratigraphic and biostratigraphic approach to Windsor Group stratigraphy is illustrated.

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